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BY
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THE IRON AND STEEL INSTITUTE.
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ON THE
INFLUENCE
OF
GAUGE LENGTH AND SECTION OF TEST BAR
ON THE
PERCENTAGE OF ELONGATION

BY

PROFESSOR W. C. UNWIN.

LONDON:
PUBLISHED FOR THE ASSOCIATION BY CROSBY LOCKWOOD & SON,
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REPORT
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INFLUENCE OF GAUGE LENGTH AND SECTION OF TEST BAR
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This Report deals with the variation of percentage of elongation with different gauge lengths and sections of test bar. It is based almost entirely on tests of steel plate test bars supplied by Mr. Colville, of the Dalzell Steel Works, Motherwell, N.B., and by Mr. Dick, of the Parkgate Steel Works. These tests cover a wide range of conditions, and no such complete information as to variation of elongation with the form of test bar has been previously available. As the results are, it is believed, valuable, whatever decision may be arrived at as to standard forms of test bars, the results have been very fully and critically discussed.

I. HISTORICAL.

For any given test bar the elongation e in a gauge length l is made up of two parts, one due to the general extension between the gauge points, which is proportional to l, and the other due to the local contraction a which is nearly independent of l Hence approximately

$$e = a + b\,l$$

where a and b are constants for a given material and test bars of the same cross section. It is obvious then that the percentage of elongation,

$$= 100\frac{e}{l} = 100\left(\frac{a}{l} + b\right),$$

diminishes for any given size of bar as the gauge length is increased. This has been long clearly enough recognised. It has not been so generally recognised that the elongation due to local contraction a depends on the cross section of the test bar, and that therefore for a given gauge length, the percentage of elongation varies with the cross section of the test bar and increases for a given gauge length as the cross section increases.

The details of the experiments and the plotted elongation curves for each bar have been omitted from this Report.

General Elongation exclusive of Local Contraction.

The difficulty of comparing the elongation of different test bars would disappear, if only the general elongation were measured, that is the elongation at the moment of maximum load, before local contraction begins. There is no easy way of doing this except by taking an autograph diagram of each test, and this is not practically possible in ordinary testing.

Elongation of Geometrically Similar Bars.

In the case of bars differing in size it is found that geometrically similar bars deform similarly and are still geometrically similar after deformation. Thus Fig. 1 shows two such similar bars, the ratio of the linear dimensions being *n*. If *ab* and *cd* are similarly placed gauge points then the percentage of elongation in a gauge length l_1 in the smaller bar and that in a gauge length $l_2 = nl_1$ in the longer bar will be the same. But then obviously the percentage of elongation in equal gauge lengths l_1 and l_3 will be different.

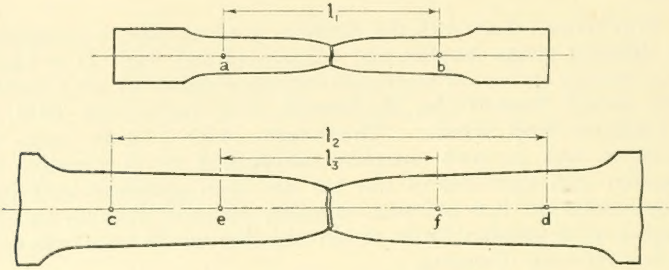


FIG. 1.

The general law that similar test bars deform similarly when broken by tension was first proved by M. Barba (Résistance des Matériaux, Memoires de la Soc. des Ing. Civiles, 1880). It follows that for cylindrical test bars the percentage of elongation is constant for a given material when the ratio of gauge length to square root of cross section is constant, or what is the same thing, when the ratio of gauge length to diameter is constant. In the case of plates of varying thickness test bars could only in strictness be geometrically similar, if a different gauge length were adopted for each thickness of plate. This would practically be very inconvenient. But it has been found that in plate test bars of a given material the percentage of elongation is nearly constant, if the relation

$$\frac{\text{gauge length}}{\text{square root of area}} = \text{constant.}$$

is satisfied, at least for any proportions of width to thickness likely to be adopted in testing. (See Appendix I.)

In 1884, Mr. W. Hackney read a paper on "The adoption of Standard Forms of Test Pieces" before the Institution of Civil Engineers. The whole object of this paper was to explain the importance of Barba's law in fixing the form of Test Bars. Mr. Hackney stated Barba's law quite correctly as follows :—"When the test pieces are either of different diameters and equal lengths or of different lengths and the same diameter, the percentages of ultimate stretching when portions of the same metal bar are tested are very different." In applying this law, however, Mr. Hackney was not consistent. He pointed out "the impossibility of comparing the results of tests made by different experimenters, on the ultimate stretching of metals, in the absence of standard forms of test pieces." In the case of cylindrical bars, following the obvious conclusion from Barba's experiments, he proposed that a fixed ratio of gauge length to diameter should be adopted as a standard. But as regards plate test bars, he clearly did not see his way, and he made no definite proposal.

II. GENERAL RESULTS OF TESTS OF STEEL PLATES FROM MOTHERWELL AND ROTHERHAM.

Tests were made on ten test bars of ship plates and ten test bars of boiler plates received from Mr. Colville, and on twenty test bars of ship plates and twenty test bars of boiler plates received from Mr. Dick. The plates varied in thickness from $\frac{1}{4}$ inch to $1\frac{1}{4}$ inch. The elongations were measured in each half inch of the length of each bar, and from these measurements the elongations and percentage of elongation in gauge lengths of 2, 4, 6, 8, 10, 12, 14 and sometimes 16 and 18 inches were calculated. The results for each bar were plotted in a curve, and measurements of these sixty curves give, for each bar tested, the percentage of elongation for any required ratio of gauge length to section, within wide limits, without any assumption, just as if it had been directly measured on a special bar. The only circumstance in any way neglected is that the nearness of enlarged ends to the gauge points does a little affect the elongation. The curves give the elongations for bars in which the enlarged ends are not very near the gauge points.

Before discussing the results it should be stated that the results on three plates have been discarded. In the case of these three plates, which were all tested across the direction of rolling, the fracture and the elongation showed that the plate was of inferior quality. It was not desirable therefore to include these results with those on good plates.

The results of these fifty-seven tests are on the whole remarkably concordant. The bars were prepared in pairs, cut from the same plate. There are differences in the results for the two bars forming a pair, due to small variations in neighbouring portions of a plate, and to variations in the distribution of elongation along each test bar, in which there are slightly harder or softer places. But the means of pairs of tests fall into very consistent series and the six series of tests tell nearly the same story.

It is stated that all Mr. Colville's bars were cut lengthways of the plate. Half Mr. Dick's bars were cut lengthways and half across the plate. As would be expected, the elongation lengthways is greater than across the plate, and this difference is fairly uniform throughout the tests. There is no great difference of elongation in the boiler plates and ship plates, except in the case of the thicker plates. The thicker boiler plates are more ductile than the thicker ship plates. As there is no other general difference of quality the results will be discussed together.

(*a.*)—Real Relative Ductility of the Motherwell and Rotherham Plates.

The percentage of elongation is customarily taken as the measure of ductility, and this in strictness should be measured on similar test bars. Hence the percentages of elongation in similar bars will first be examined and then the elongation in bars of other proportions.

The Committee on Materials used in Ships and their Machinery have decided on an 8 in. gauge length. From the curves mentioned above the percentages of elongation have been measured for an 8 in. gauge length and for bars of one-half square inch section ($l = 11{\cdot}3 \sqrt{a}$) which is the German standard form. Also for an 8 inch gauge length and for bars of one square inch of section ($l = 8 \sqrt{a}$).

The whole of the detailed results for these two cases are given in the Appendix II., Tables XVI., XVII., XVIII., XIX. It is desirable that these should be compared with the mean results of all the tests taken together given below. It is important as showing the general concordance of the results, that the separate series in every case are in fair agreement with the general mean of all.

In Diagram VII., the percentage of elongation for each thickness of plate, for each of the six series of tests and both for bars of one-half and one inch section are plotted. It will be seen that the general form of the curves for all the bars is nearly the same and that the curves for half-inch bars are nearly parallel to the curves for one inch bars.*

---

* The points on the K L curves for $1\frac{1}{4}$ inch plate are not strictly in their true position. The results on the Parkgate $1\frac{1}{4}$ inch boiler plate, tested across the plate, were excluded because of the crystalline fracture and small elongation. If these had been included the end points of curves K L would have been much lower.

The following Tables give the mean elongations for the three series of ship plates and the three series of boiler plates.

SHIP PLATES.

Thickness. Inches.	Mean Elongation per cent. in 8 inches.	
	Plates of half a square inch section.	Plates of one square inch section.
¼	22·7	25·4
⅜	26·0	29·1
⅝	24·7	26·6
⅞	22·3	24·9
1¼	19·8	22·6
Mean of all ...	23·1	25·7

BOILER PLATES.

Thickness. Inches.	Mean Elongation per cent. in 8 inches.	
	Plates of half a square inch section.	Plates of one square inch section.
¼	22·7	26·2
⅜	26·9	29·4
⅝	25·6	28·5
⅞	24·3	27·2
1¼	24·6	27·4
Mean of all ...	24·8	27·7

The elongations when measured on constant gauge length and constant area tell a quite clear story, and the following conclusions may be drawn :—

(*a.*) The *relative* ductility is practically the same, whether the test bars are one inch or half an inch area.

(*b.*) The mean difference of percentage of elongation in the series of one inch, and the series of half inch bars is 2·6 per cent. in the ship plates, and 2·9 per cent. in the boiler plates.

(*c.*) The plates below ⅜ inch thick have less ductility than thicker plates. A special rule therefore is required for plates under ⅜ inch thick.

(*d.*) For plates over ⅝ inch thick the ductility diminishes as the thickness increases. A special rule may have to be adopted for plates more than ⅞ inch thick, if standard test bars have constant area.

(*e.*) The falling off of ductility with increase of thickness is less in the boiler plates than in the ship plates, so that while ⅝ inch boiler and ship plates have about the same percentage of elongation, 1¼ inch boiler plates have about 5 per cent. more percentage of elongation than the corresponding ship plates.

(*b*) Elongation of Test Bars of the same width for all Thicknesses.

Tables XXI., XXIV., in the Appendix III., give the details of elongation for boiler and ship plates in each series, when the gauge length is 8 inches, and the width of test bars 2 ins. The results are plotted in diagram VIII.

The following are the mean results for the three series of ship plates, and the three series of boiler plates. The difference of elongation in bars of constant width and that of bars of constant area is considered as the error of the former mode of measurement.

Comparison of Elongations measured on bars 2 ins. wide, and those on bars of gauge length = 11·3 $\sqrt{\text{area}}$.

SHIP PLATES.

	Thickness of Plate. Inches.	Elongation % in 8 ins. when $l = 11{\cdot}3\sqrt{a}$.	Elongation % in 8 ins. of bar 2 ins. wide.	Difference or error.	Error in per cent. of total elongation.
Messrs. Colville & Sons, Motherwell.	¼	23·9	23·9	0·0	0·0
	⅜	28·4	30·1	1·7	6·0
	⅝	26·6	29·6	3·0	11·3
	⅞	24·7	30·4	5·7	23·1
	1¼	17·8	24·0	6·2	34·8
Parkgate Iron & Steel Co. Lengthways of Plate.	¼	23·6	23·6	0·0	0·0
	⅜	25·6	27·0	1·4	5·5
	⅝	23·2	27·3	4·1	17·7
	⅞	20·4	24·6	4·2	20·6
	1¼	20·5	26·6	6·1	29·8
Parkgate Iron & Steel Co. Across Plate.	¼	20·5	20·5	0·0	0·0
	⅜	24·1	26·0	1·9	7·9
	⅝	22·4	25·7	3·3	14·7
	⅞	21·7	28·0	6·3	29·0
	1¼	21·2	28·2	7·0	33·0

Comparison of elongations measured on bars two inches wide and those on Standard Bars of gauge length = 11·3 $\sqrt{\text{area}}$.

BOILER PLATES.

	Thickness of Plate. Inches.	Elongation % in 8 ins. when $l = 11\cdot3\sqrt{a}$.	Elongation % in 8 ins. of bar 2 ins. wide.	Difference or error.	Error in per cent. of total elongation.
Messrs. Colville & Sons, Motherwell.	¼	28·9	28·9	0·0	0·0
	⅜	29·2	30·7	1·5	5·1
	⅝	26·2	29·9	3·7	14·1
	⅞	25·8	31·4	5·6	21·7
	1¼	23·5	31·2	7·7	32·8
Parkgate Iron & Steel Co. Lengthways of Plate.	¼	22·9	22·9	0·0	0·0
	⅜	25·8	27·2	1·4	5·4
	⅝	25·3	29·3	4·0	15·8
	⅞	24·7	30·2	5·5	22·3
	1¼	25·7	33·0	7·3	28·4
Parkgate Iron & Steel Co. Across Plate.	¼	16·2	16·2	0·0	0·0
	⅜	25·6	26·7	1·1	4·3
	⅝	25·3	29·3	4·0	15·8
	⅞	22·3	28·5	6·2	27·8
	1¼	...	...	...	.

(c)—Variation of Elongation with Width of Test Bar.

As it has been suggested to allow considerable variation in the width of test bar, it is desirable to examine the probable effect of this on the percentage of elongation. The percentages of elongation for values of $l/\sqrt{a}$ corresponding to an 8 inch gauge length and widths of test bar of 1½, 2, and 2½ inches, have been measured from the plotted curves for all the sixty bars tested. The detailed results are given in the Appendix III., Tables XX. to XXV. The results are very consistent on the whole, so that an examination of the mean values for the three sets of ship plates and the three sets of boiler plates is sufficient for the present purpose. The following table gives a summary of the results.

Mean Elongations Per Cent. in 8 inches, with Different Widths of Test Bar.

SHIP PLATES.

Thickness of Plate. Inches.	Elongations per cent.			Differences of Percentage.	
	Test Bar 1½ ins. wide.	Test Bar 2 ins. wide.	Test Bar 2½ ins. wide.	1½ ins. and 2 ins.	2 ins. and 2½ ins.
¼	21·7	22·7	23·5	1·0	0·8
⅜	26·4	27·7	28·9	1·3	1·2
⅝	26·4	27·5	28·6	1·1	1·1
⅞	26·2	27·7	28·9	1·5	1·2
1¼	25·2	26·3	27·3	1·1	1·0

It will be seen that the differences of percentage of elongation are pretty constant, and average 1·1 per cent. for each ½ inch width.

BOILER PLATES

Thickness of Plate. Inches.	Elongations per cent.			Differences of Percentage.	
	Test Bar 1½ ins. wide.	Test Bar 2 ins. wide.	Test Bar 2½ ins. wide.	1½ ins. and 2 ins.	2 ins. and 2½ ins.
¼	20·9	22·7	23·7	1·8	1·0
⅜	27·1	28·2	29·2	1·1	1·0
⅝	28·2	29·5	30·8	1·3	1·3
⅞	28·6	30·0	31·3	1·4	1·3
1¼	30·6	32·1	33·8	1·5	1·7

The differences here are also pretty constant, but a little larger than for the ship plates. The average difference is 1·34 per cent. for each ½ inch width.

It will be seen that if test bars are allowed to vary in width from 1½ to 2½ inches, it may be expected that the wider plates will have, on the average, between 2½ and 3 per cent. more elongation per cent. than the narrower ones, a difference which perhaps for commercial testing might be permitted.

These results are deduced from the curves and some confirmation may not be unwelcome. Mr. Denny has made direct experiments on bars of different widths, the results of which are given in the table below. The results are not quite consistent, the plates apparently differing somewhat in quality.

The mean difference of percentage, however, does not seem very different from that given above. From Mr. Denny's curves the percentage of elongation for bars of one square inch in section has also been measured, as a criterion of the relative quality of the plates. The ¼ inch plate seems to be better than usual, and the ½ inch plate not so good.

Variation of Elongation with Width of Test Bar.

PLATES TESTED BY MESSRS. W. DENNY & BROS.

Thickness in Inches.	Width in Inches.	Value of $\frac{l}{\sqrt{a}}$	Elongation per cent. in 8 inches.	Difference per ½ in. width of bar.	Elongation per cent. of bar 1 square inch area.	
¼	¾	18·2	20·5	1·4	27·1	Mean 27·8
	1½	12·9	23·5		28·6	
	2½	9·9	25·5		27·8	
½	¾	12·7	19·3	1·5	22·0	Mean 24·3
	1½	9·1	25·8		27·4	
	2½	7·1	24·5		23·4	
¾	¾	10·7	22·9	1·4	25·8	Mean 26·9
	1½	7·5	26·3		25·8	
	2	6·6	26·4		29·0	
1	¾	9·2	26·0	1·8	26·2	Mean 28·1
	1	7·9	31·1		31·0	
	1½	6·5	28·8		29·0	

The ½ in. plate is noted as a bad plate with flaky fracture.

The following experiments on the influence of width of test bar were made some time since at the Central Technical College. The bars were all cut from one plate and they were planed all over in order that the measurements might be more exact.

Elongations of Bars of Different Widths.

BARS CUT FROM THE SAME STEEL PLATES AND SURFACES PLANED TO REMOVE SCALE.

GENERAL RESULTS.

No. of Bar.	Dimensions in Inches.			Breaking Stress. Tons per square inch.	Mean Breaking Stress. Tons per square inch.	Elongation in 8 inches. Per cent.	Mean Elongation in 8 inches. Per cent.	Differences of Elongation per cent. per half inch width.	
	Width.	Thickness.	Area.						
2318	3·001	·397	1·1899	26·84		31·56			
2319	3·004	·394	1·1836	26·92	26·88	31·88	31·94	0·91	
2320	3·003	·396	1·1892	26·87		32·38			
2321	2·000	·399	0·7980	26·88		31·63			Mean
2322	2·001	·400	0·8006	27·16	27·02	28·88	30·13		1·48
2323	2·003	·396	0·7930	27·01		29·88			
2324	1·002	·396	0·3968	27·42		26·69		2·05	
2325	1·001	·393	0·3934	27·96	27·65	26·13	26·02		
2326	1·005	·392	0·3940	27·57		25·25			

The differences of tenacity which are not large, but regularly vary with the width, may be due to more equal distribution of stress on the narrower bars.

The mean difference of elongation per cent. is 1·48 per half inch width of test bar.

III.—DISCUSSION OF PROPOSALS AS TO STANDARD FORM OF TEST BARS.

General Considerations.

There are three possible general rules which may be adopted in settling the standard forms of test bar. But there are practical objections to rigidly applying them.

(*a.*) *Gauge length varied, so that $l/\sqrt{a}$ is kept constant whatever the section of the bar.*—If the gauge length is varied most of the difficulty in applying the principle of "geometrically similar" test bars vanishes. In fact in Germany, when the standard form of half inch section and eight inch gauge length is departed from, proportional bars are used, the gauge length being varied so that the standard relation $l = 11·3 \sqrt{a}$ is still complied with. But the Committee have decided on a fixed gauge length, and the objections on the ground of cost to a variable gauge length seem insuperable in commercial tests.

(*b.*) *Fixed gauge length and fixed area of section of test bar.*—If this rule were adopted, a section of one-half square inch or one square inch might be adopted for an eight inch gauge length, or, since it has been shown that the difference of percentage of elongation in half inch and one inch bars is under 3 per cent., standard bars might be defined as bars of 8 inch gauge length, and not more than 1 square inch or less than one half square inch section. This rule would be quite satisfactory from the scientific point of view.

Practically it would be inconvenient for very thin and very thick plates. The following table gives the widths of test bars for various thicknesses of plate.

Thickness of Plate. Inches.	Width of Test Bar.	
	0·5 sq. in. in Area.	1·0 sq. in. in Area.
¼	2·00	4·00
⅜	1·33	2 66
⅝	0·80	1·60
⅞	0·57	1·14
1¼	0·40	0·80
1½	0·33	0·66

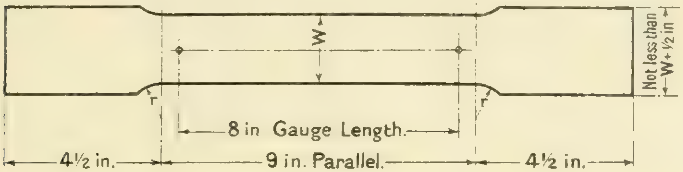
(*c*) *Fixed gauge length and fixed width of test bar.*—There is a practical objection to carrying out this rule rigidly also, namely, that for very thick plates the sectional area is so large that ordinary testing machines will not break the test bars. The following table gives the breaking weights of test bars of different thicknesses for steel of 36 tons tenacity, the lowest which it would seem necessary to provide for.

Thickness of Plate. Inches.	Breaking Strength of Test Bar 2 ins. wide.
¼	18 tons
⅜	27 ,,
⅝	45 ,,
⅞	63 ,,
1¼	90 ,,
1¾	126 ,,

The discussion seems to show that, if plates of all thicknesses are considered from the thinnest to the thickest, no one rule can be rigidly adopted, there must be a compromise. Now by far the greatest weight of plates manufactured are between ⅜ inch and ⅞ inch thick (inclusive). If standard proportions could be settled for these plates first, then necessary modifications for thinner and thicker plates could easily be arranged.

General Form of Test Bar.

If the question of width of test bar is put aside for the moment there is not much room for discussion as to the general form of the test bar. The only point which should be borne in mind is that nearness of enlarged ends to the gauge length diminishes the percentage of elongation. Hence the parallel part should be rather longer than the gauge length and curves should join the parallel part to the enlarged ends.



Suggested Standards.

Plan I.—The plan which would accord best with the scientific principle that the tests should show the real quality of the material would be this :—

For plates from $\frac{3}{8}$ inch to $\frac{7}{8}$ inch in thickness (inclusive), the gauge length shall be 8 inches and the cross-section of the test bar shall not exceed one square inch.

The following Table shows some cases of this rule :—

Thickness of Plate. Inches.	Greatest width of Test Bar. Inches.	Value of $\frac{l}{\sqrt{a}}$	Elongation per cent. in the tests made.	
			Ship Plates.	Boiler Plates.
$\frac{3}{8}$	$2\frac{2}{3}$	8·0	29·1	29·4
$\frac{5}{8}$	$1\frac{3}{5}$	,,	26·6	28·5
$\frac{7}{8}$	$1\frac{1}{7}$	,,	24·9	27·2

All such bars would break in a fifty-ton machine. For very thin plates it would be desirable to fix a rather less maximum area and for plates above $\frac{7}{8}$ inch thick, a rather larger area.

Plan II.—The plan may be adopted of fixing the maximum width of test bar. The rule might then be as follows :—

For plates from $\frac{3}{8}$ inch to $\frac{7}{8}$ inch in thickness inclusive, the gauge length shall be 8 inches, and the width of test bar not more than 2 inches.

The following Table shows some cases of this rule :—

Thickness of Plate. Inches.	Greatest width of Test Bar. Inches.	Value of $\frac{l}{\sqrt{a}}$	Elongation per cent. in the tests made.	
			Ship Plates.	Boiler Plates.
$\frac{3}{8}$	2	9·2	27·7	28·2
$\frac{5}{8}$	2	7·2	27·5	29·5
$\frac{7}{8}$	2	6·1	27·7	30·0

For plates of less than ⅜ inch thick, it would be better to make the greatest width 2½ inches, and for plates more than ⅝ inch thick, to make the greatest width 1½ inches.

IV. FURTHER DATA FROM SOME TESTS OF ANNEALED AND UNANNEALED PLATES WITH VARYING PERCENTAGES OF CARBON, RECEIVED FROM THE PARKGATE IRON AND STEEL WORKS, ROTHERHAM.

Mr. F. W. Dick was good enough to supply some test bars cut from plates containing varying percentages of carbon, to be tested for the information of the Committee. Half these plates were unannealed, and half were annealed. The percentage of carbon varied from 0·32 to 0·60.

The tests on these plates were made in the same way as those already given. The extensions were measured in each half inch, and the extension in various gauge lengths from 2 to 14 inches was computed from the measurements. Plotting these results the extension for any gauge length and area of cross section can be found as in the preceding cases. Hence these results throw light on the question of the variation of elongation both with variation of section and variation of hardness.

The following are the general results of these tests :—

General Results.

Percentage of Carbon.	Thickness of Plate.	Breaking Stress per sq. in.	Mean Breaking Stress.	Elongation in 8 ins.	Mean Elongation.
	Ins.	Tons.	Tons.	Per cent.	Per cent.
		UNANNEALED PLATES.			
0·32	¼	35·62	33·97	17·7	20·0
	½	33·85		21·9	
	¾	32·43		20·4	
0·48	¼	39·41	38·09	15·8	16·0
	½	38·45		16·1	
	¾	36·42		16·0	
0·60	¼	47·39	47·39	13·8	13·8
		ANNEALED PLATES.			
0·32	¼	29·85	30·33	23·6	22·0
	½	30·43		22·4	
	¾	30·72		20·0	
0·48	¼	34·03	33·46	19·4	20·3
	½	33·38		21·6	
	¾	32·98		19·8	
0·60	¼	40·94	39·23	16·9	17·3
	½	38·78		17·9	
	¾	37·98		17·0	

The elongations in this Table are those of the actual bars varying in section from 0·41 to 0·76 sq. ins. area.

Mean Difference between Unannealed and Annealed Bars.

Percentage of Carbon.	Mean Breaking Stress per sq. in.		Difference.	Mean Elongation in 8 ins.		Difference.
	Unannealed.	Annealed.		Unannealed.	Annealed.	
	Tons.	Tons.		Per cent.	Per cent.	Per cent.
0·32	33·97	30·33	3·64	20·0	22·0	2·0
0·48	38·09	33·46	4·63	16·0	20·3	4·3
0·60	47·25	39·23	8·02	13·8	17·3	3·5

As is ordinarily the case the breaking stress is lowered and the ductility increased by annealing. The difference increases with the hardness of the steel.

From the measurements of elongation it is next possible to find the elongation for any variation of the cross section of the bars. The results in the following table have been deduced from the curves for each thickness of bar and each percentage of carbon. They are calculated for the same widths of bar as in the tables above. They are obtained without any theoretical assumption except that the percentage of elongation is constant in geometrically similar bars.

Variation of Elongation both with variation of Dimensions of Bar and of percentage of Carbon.

Percentage of Carbon.	Thickness of Plate.	Elongations in 8 inches for the following widths of Test Bar.					
		1½ ins.	2 ins.	2½ ins.	1½ ins.	2 ins.	2½ ins.
	Ins.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
		UNANNEALED PLATES.			ANNEALED PLATES.		
0·32	¼	15·4	16·4	17·2	22·8	23·8	24·6
	½	21·8	23·0	24·0	22·0	23·1	24·1
	¾	22·0	23·3	24·6	21·7	23·1	24·3
0·48	¼	15·7	16·5	17·3	19·1	19·7	20·2
	½	15·8	17·0	18·0	20·9	22·0	22·9
	¾	16·3	17·5	18·6	21·3	22·7	23·9
0·60	¼	13·2	14·0	14·7	16·1	16·9	17·7
	½	—		—	17·5	18·4	19·1
	¾	—	—	—	18·2	19·5	20·5

NOTE.—The author has found (since this report was written) a general relation between the percentage of elongation, and gauge length and cross section of bar. If e is the percentage of elongation in a gauge length l for a bar of cross section A, then

$$e = \frac{c\sqrt{A}}{l} + b$$

Where the first term on the right is the percentage of elongation due to local contraction, and the second is the percentage of general elongation, c and b are constants for any given quality of material.

APPENDIX I.

That geometrically similar bars deform similarly appears to be a rational rule independent of experiment. But it has been fully verified for cylindrical bars both in tension and compression. The following is a Table of Tests by Barba. For all the bars, putting l = gauge length, a = sectional area, d = diameter.

$$l = 8{\cdot}2\sqrt{a} \text{ and } l = 7{\cdot}24d.$$

The dimensions are in millimetres.

Mild Steel.

Diameter.	Gauge Length.	Elongation per cent.
6·90	50	32·8
10·35	75	33·2
13·80	100	33·0
17·25	125	33·5
20·70	150	33·6
24·15	175	33·2
27·60	200	33·0
31·05	225	34·0

For the case of plate test bars the experimental verification is less easy because it is difficult to obtain plate specimens, of different widths and thickness, of exactly the same quality and because in the ordinary rough method of testing with wedge grips it is difficult to ensure uniform distribution of stress on the section of fracture. The following table gives some experiments by Bauschinger which show that for a large variation of form of cross section the variation of elongation is small, if the ratio of gauge length to square root of area is constant.

Influence of Shape of Section on Elongation.

Elongations of Flat Bars cut from one Plate when $l = 8{\cdot}5\sqrt{a}$.

Cross Section. Ratio of Width to Thickness.	Elongation per cent.	
	Series I.	Series II.
1·3	—	33·2
1·4	31·0	—
1·5	—	33·3
1·7	31·7	33·5
1·8	33·0	—
2·1	31·8	33·2
3·0	32·0	34·5

APPENDIX II.

Ship Plates.—Table XVI.

Mean Elongations per cent. for Gauge Length = 11·3 $\sqrt{a}$.

This is the standard German proportion, and corresponds to an area of 0·5 square inch for an 8 inch gauge length.

Thickness of Plate. Inches.	Messrs. Colville and Sons, Ltd.	Mean.	Parkgate Iron and Steel Co. Lengthways of Plate.	Mean.	Parkgate Iron and Steel Co. Across Plate.	Mean.
¼	25·3 22·5	23·9	21·6 25·6	23·6	20·9 20·0	20·5
⅜	28·0 28·7	28·4	25·3 25·9	25·6	25·0 23·2	24·1
⅝	24·9 28·3	26·6	24·3 22·1	23·2	22·4 22·3	22·4
⅞	23·0 26·3	24·7	20·9 19·8	20·4	— 21·7	21·7
1¼	17·3 18·3	17·8	18·9 22·0	20·5	22·3 20·0	21·2

Mean Elongation.

¼ in. Plate	22·7
⅜ ,, ,, ...	26·0
⅝ ,, ,, ...	24·7
⅞ ,, ,, ...	22·3
1¼ ,, ,, ...	19·8
Mean of all ...	23·1

Boiler Plates.—Table XVII.

Mean Elongations per cent. for Gauge Length = 11·3 $\sqrt{a}$.

This is the standard German proportion, and corresponds to an area of 0·5 square inch for an 8 inch gauge length.

Thickness of Plate. Inches.	Messrs. Colville and Sons, Ltd.	Mean.	Parkgate Iron and Steel Co. Lengthways of Plate.	Mean.	Parkgate Iron and Steel Co. Across Plate.	Mean.
¼	27·6 30·2	28·9	21·3 24·4	22·9	16·8 15·5	16·2
⅜	28·4 30·0	29·2	27·0 24·5	25·8	27·5 23·7	25·6
⅝	26·3 26·2	26·2	23·3 27·3	25·3	25·1 25·4	25·3
⅞	25·3 26·3	25·8	23·7 25·6	24·7	21·3 23·3	22·3
1¼	22·0 25·0	23·5	24·6 26·7	25·7	—	—

Mean Elongation.

¼ in. Plate	22·7
⅜ ,, ,, ...	26·9
⅝ ,, ,, ...	25·6
⅞ ,, ,, ...	24·3
1¼ ,, ,, ...	24·6*
Mean of all ...	24·8

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* As tests of the 1¼ inch plate, across the plate, are excluded, this figure is too high relatively to the others which include tests across the plate.

Ship Plates.—Table XVIII.

Mean Elongations per cent. for Gauge Length = 8 $\sqrt{a}$.

This corresponds to an area of 1 square inch for an 8 inch gauge length.

Thickness of Plate. Inches.	Messrs. Colville and Sons, Ltd.	Mean.	Parkgate Iron and Steel Co. Lengthways of Plate.	Mean.	Parkgate Iron and Steel Co. Across Plate.	Mean.
¼	28·5	26·9	23·6	25·8	23·7	23·4
	25·3		28·0		23·0	
[illegible]	30·9	31·5	27·6	28·4	28·2	27·4
	32·0		29·1		26·5	
[illegible]	27·2	28·6	28·1	26·5	24·5	24·7
	30·3		24·8		24·8	
[illegible]	25·0	27·5	22·1	22·3	—	25·0
	29·9		22·4		25·0	
1¼	19·4	20·5	20·9	22·6	25·0	24·6
	21·5		24·3		24·1	

Mean Elongation.

¼ in. Plate	25·4
[illegible] ,, ,, ...	29·1
[illegible] ,, ,, ...	26·6
[illegible] ,, ,, ...	24·9
1¼ ,, ,, ...	22·6
Mean of all ...	25·7

Boiler Plates.—Table XIX.

Mean Elongations per cent. for Gauge Length = 8 $\sqrt{a}$.

This corresponds to an area of 1 square inch for an 8 inch gauge length.

Thickness of Plate. Inches.	Messrs. Colville and Sons, Ltd.	Mean.	Parkgate Iron and Steel Co. Lengthways of Plate.	Mean.	Parkgate Iron and Steel Co. Across Plate.	Mean.
[illegible]	31·7	33·1	24·7	26·4	19·7	19·0
	34·4		28·0		18·2	
[illegible]	31·5	31·9	30·8	28·7	29·1	27·6
	32·3		26·5		26·0	
[illegible]	28·0	28·8	26·3	28·3	28·0	28·4
	29·6		30·2		28·7	
[illegible]	28·1	28·2	25·8	27·4	24·6	25·9
	28·2		29·0		27·1	
1¼	24·5	26·1	28·1	28·8	—	—
	27·7		29·5		—	

Mean Elongation.

¼ in. Plate	26·2
[illegible] ,, ,, ...	29·4
[illegible] ,, ,, ...	28·5
[illegible] ,, ,, ...	27·2
1¼ ,, ,, ...	27·4*
Mean of all ...	27·7

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* As tests of the 1¼ inch plate, across the plate, are excluded, this figure is too high relatively to the others which include tests across the plate.

APPENDIX III.

Ship Plates.—Table XX.

Mean Elongations per cent. for an 8 inch gauge length and a constant width of test bar of 1½ inches.

Thickness of Plate. Inches.	Messrs. Colville and Sons, Ltd.	Mean.	Parkgate Iron and Steel Co. Lengthways of Plate.	Mean.	Parkgate Iron and Steel Co. Across Plate.	Mean.
¼	24·3 21·5	22·9	21·0 24·3	22·7	19·8 19·1	19·5
⅜	28·3 29·4	28·9	24·9 26·3	25·6	25·6 23·7	24·7
⅝	27·1 30·0	28·6	27·4 24·6	26·0	24·4 24·6	24·5
⅞	26·2 31·7	29·0	23·0 23·7	23·4	26·3 —	26·3
1¼	21·7 24·4	23·1	23·5 27·2	25·4	28·0 26·1	27·1

Mean Elongation.

¼ in. Plate	21·7
⅜ ,, ,, ...	26·4
⅝ ,, ,, ...	26·4
⅞ ,, ,, ...	26·2
1¼ ,, ,, ...	25·2
Mean of all ...	25·2

Ship Plates.—Table XXI.

Mean Elongations per cent. for an 8 inch gauge length and a constant width of test bar of 2 inches.

Thickness of Plate. Inches.	Messrs. Colville and Sons, Ltd.	Mean.	Parkgate Iron and Steel Co. Lengthways of Plate	Mean.	Parkgate Iron and Steel Co. Across Plate.	Mean.
¼	25·3 22·6	23·9	21·6 25·5	23·6	20·9 20·0	20·5
⅜	29·4 30·7	30·1	26·2 27·7	27·0	27·0 25·0	26·0
⅝	27·9 31·2	29·6	29·0 25·5	27·3	25·5 25·8	25·7
⅞	27·4 33·3	30·4	24·0 25·1	24·6	28·0 —	28·0
1¼	22·6 25·4	24·0	24·8 28·4	26·6	29·2 27·1	28·2

Mean Elongation.

¼ in. Plate	22·7
⅜ ,, ,, ...	27·7
⅝ ,, ,, ...	27·5
⅞ ,, ,, ...	27·7
1¼ ,, ,, ...	26·3
	26·4

Ship Plates. Table XXII.

Mean Elongations per cent. for an 8 inch gauge length and a constant width of test bar of 2½ inches.

Thickness of Plate. Inches.	Messrs. Colville and Sons, Ltd.	Mean.	Parkgate Iron and Steel Co. Lengthways of Plate.	Mean.	Parkgate Iron and Steel Co. Across Plate.	Mean.
¼	26·1 23·4	24·8	22·0 26·5	24·3	21·8 20·8	21·3
⅜	30·5 31·8	31·2	27·8 28·8	28·3	28·0 26·3	27·2
⅝	28·8 32·3	30·6	30·3 26·3	28·3	26·6 26·9	26·8
⅞	28·4 34·9	31·7	25·0 26·4	25·7	29·4	29·4
1¼	23·4 26·2	24·8	26·0 29·5	27·8	30·5 28·0	29·3

Mean Elongation.

¼ in. Plate	23·5
⅜ ,, ...	28·9
⅝ ,, ...	28·6
⅞ ,, ...	28·9
1¼ ,, ...	27·3
Mean of all .	27·3

Boiler Plates.—Table XXIII.

Mean Elongations per cent. for an 8 inch gauge length and a constant width of test bar of 1½ inches.

Thickness of Plate. Inches.	Messrs. Colville and Sons, Ltd.	Mean.	Parkgate Iron and Steel Co. Lengthways of Plate.	Mean.	Parkgate Iron and Steel Co. Across Plate.	Mean.
¼	26·1 28·5	27·3	20·0 —	20·0	16·1 14·6	15·4
⅜	28·7 30·3	29·5	27·5 24·3	25·9	27·7 24·1	25·9
⅝	27·8 29·3	28·6	26·0 30·0	28·0	27·7 28·5	28·1
⅞	29·5 29·5	29·5	26·9 30·5	28·7	26·5 28·6	27·6
1¼	27·6 31·3	29·5	32·3 31·0	31·7	—	—

Mean Elongation.

¼ in. Plate	20·9
⅜ ,, ...	27·1
⅝ ,, ...	28 2
⅞ ,, ...	28·6
1¼ ,, ,, ...	30·6*
Mean of all ..	27·1

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* As tests of the 1¼ inch plate, across the plate, were excluded, this figure is too high relatively to the others which include tests across the plate.

Boiler Plates. Table XXIV.

Mean Elongations per cent. for an 8 inch gauge length and a constant width of test bar of 2 inches.

Thickness of Plate. Inches.	Messrs. Colville and Sons, Ltd.	Mean.	Parkgate Iron and Steel Co. Lengthways of Plate.	Mean.	Parkgate Iron and Steel Co. Across Plate.	Mean.
¼	30·2 27·7	28·9	21·3 24·4	22·9	16·8 15·5	16·2
⅜	31·3 30·0	30·7	29·1 25·3	27·2	28·3 25·1	26·7
⅝	28·7 31·0	29·9	27·3 31·2	29·3	29·0 29·6	29·3
⅞	31·5 31·2	31·4	28·2 32·2	30·2	27·0 30·0	28·5
1¼	29·4 33·0	31·2	33·9 32·0	33·0	— —	—

Mean Elongation.

¼ in. Plate	22·7
⅜ „ „	28·2
⅝ „ „	29·5
⅞ „ „	30·0
1¼ „ „	32·1*
Mean of all ..	28·5

* As the results of the tests across the plate for 1¼ inch plates have been excluded, this figure is too high relatively to the others which include tests across the plate.

Boiler Plates.—Table XXV.

Mean Elongations per cent. for an 8 inch gauge length and a constant width of test bar of 2½ inches

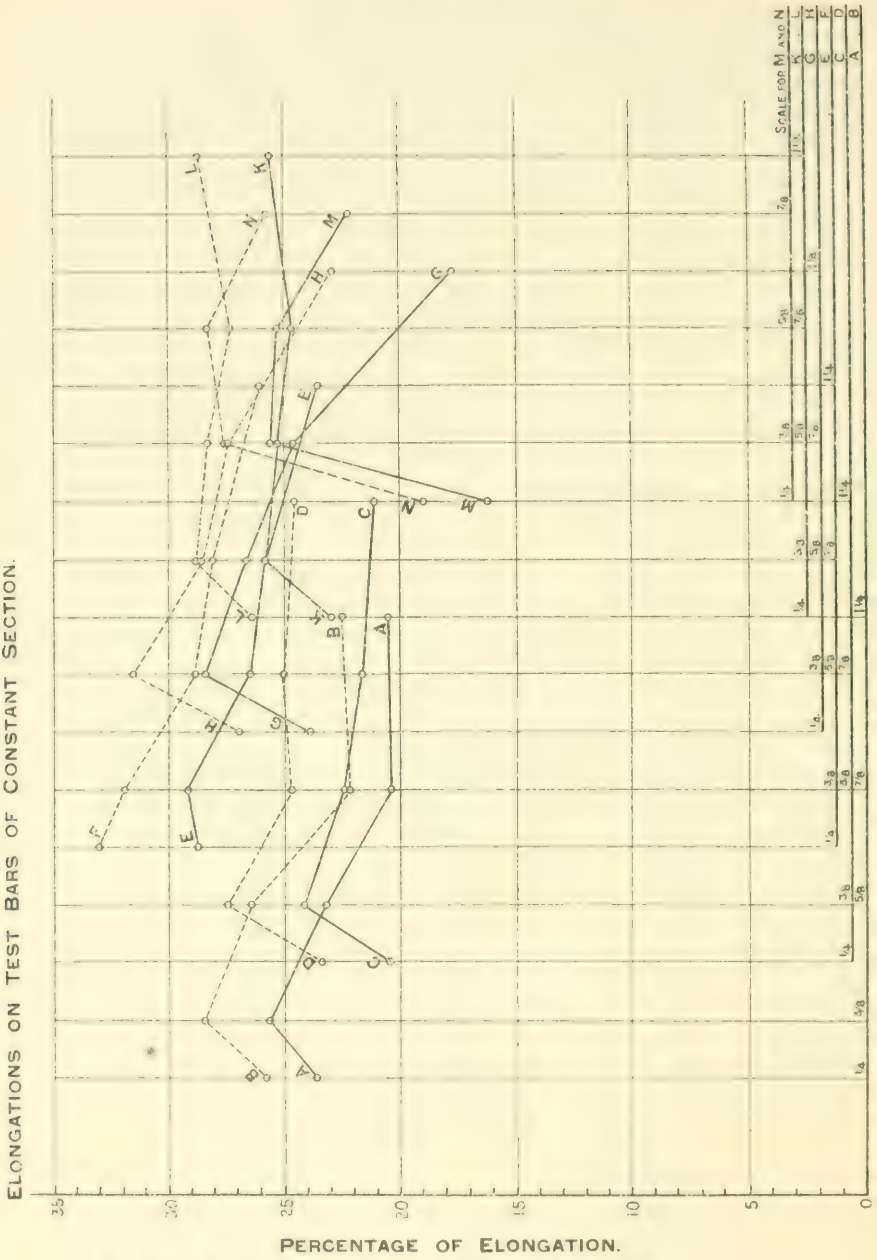
Thickness of Plate. Inches.	Messrs. Colville and Sons, Ltd.	Mean.	Parkgate Iron and Steel Co. Lengthways of Plate.	Mean.	Parkgate Iron and Steel Co. Across Plate.	Mean.
¼	28·8 31·5	30·2	22·4 25·4	23·9	17·5 16·3	16·9
⅜	31·2 32·2	31·7	30·5 26·2	28·4	29·0 25·9	27·5
⅝	29·9 32·9	31·4	28·6 32·5	30·6	30·0 30·5	30·3
⅞	33·3 32·8	33·1	29·3 34·0	31·6	27·6 31·0	29·3
1¼	31·5 35·0	33·3	35·5 33·1	34·3	— —	—

Mean Elongation.

¼ in. Plate	23·7
⅜ „	29·2
⅝ „	30·8
⅞	31·3
1¼	33·8*
Mean of all ..	29·8

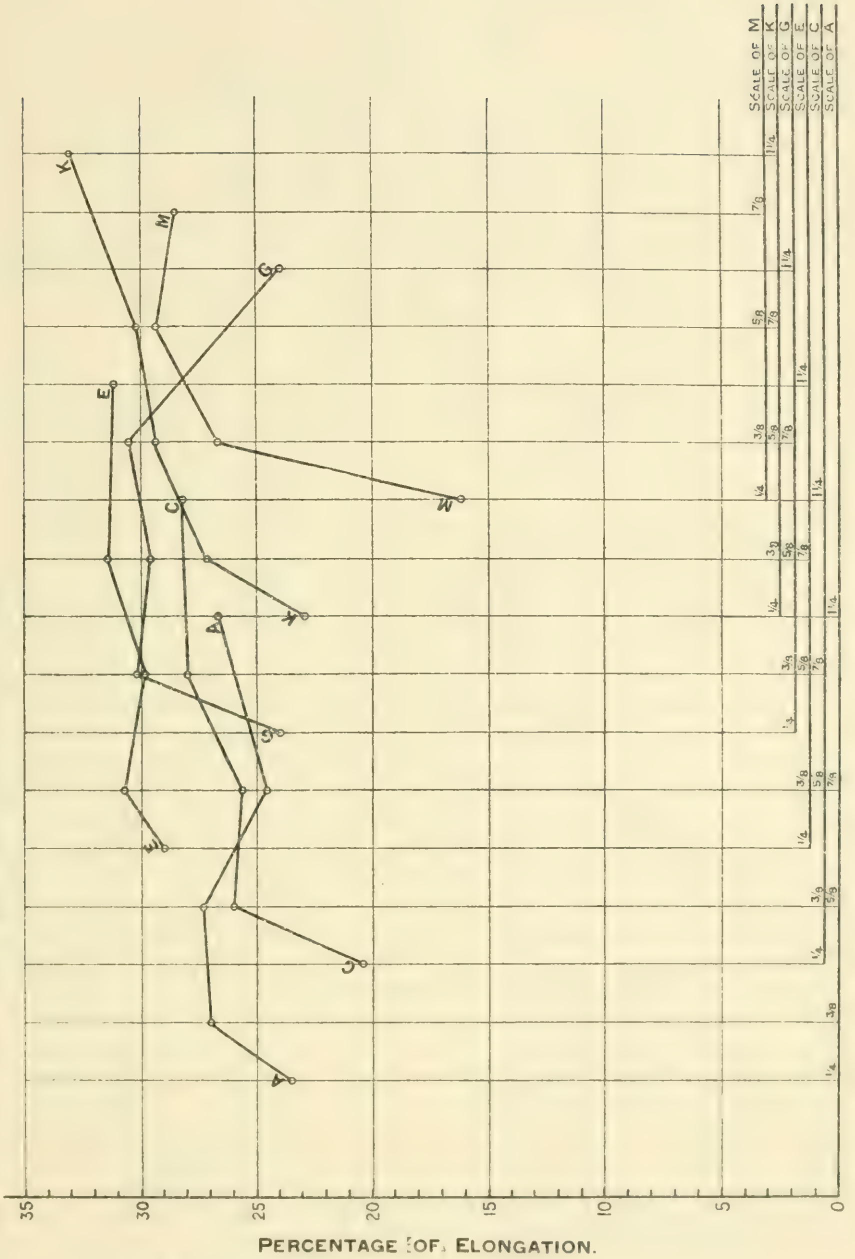
* As tests on the 1¼ inch plate, across the plate, are excluded, this figure is too high relatively to the others which include tests across the plate.

Diagram VII.



Bars of 0·5 sq. in. Section are shown in full lines
Bars of 1·0 sq. in. Section are shown in dotted lines.

Diagram VIII.



ELONGATIONS OF TEST BARS OF CONSTANT WIDTH.

PERCENTAGE [OF] ELONGATION.

Width of Test Bars 2 inches

British Engineering Standards Association.

PRICE LIST
OF
BRITISH STANDARD SPECIFICATIONS AND REPORTS.

FEBRUARY, 1920.

(This List cancels all previous Lists.)

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